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JET TRANSPORT ECONOMICS - INFLUENCE ON AIRPORT AND AIRWAY

by J. G. Borger

AIR TRANSPORT DIVISION

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JET TRANSPORT ECONOMICS—INFLUENCE ON AIRPORT AND AIRWAY

J. G. Borger
Pan American World Airways, Inc.

Introduction

Air transport's primary product is speed—speed in transporting the businessman, the traveller, mail and more and more cargo anywhere in the world. Travel and transport is by its very nature burdensome. The Magic Carpet of old that would whisk one anywhere almost instantaneously is still the ultimate ideal of the traveller and shipper.

The airplane is bringing us nearer to this ideal. Many people who would never have made the trip before—because it took too long or cost too much—travelled to Europe last summer. More will do it this summer, because the speed of air travel has not only made it possible to tour Europe within a two weeks vacation, but the engineering development of the transport airplane has brought fares down to a level an average man and his wife can afford. A trip to Europe is no longer something one skimped and saved to do once in a lifetime and then took 3 to 6 months to enjoy. And Europe isn't the only place, for such tourist services have been introduced elsewhere and are equally successful.

It has taken the aviation industry 25 years to raise the average cruising speed of air transport from 100 miles per hour to a little over 300. Jet transports cruising at 450 miles per hour are already in service, and 550 mile per hour airplanes are on the drawing boards and should be in service in less than 10 years. The jet transport is not just around the corner, it is here now, and here to stay.

British Overseas Airways Corporation (BOAC) will observe the first anniversary of scheduled jet transport operation in another two months. Today one can ride from London to Rome and on to Johannesburg, South Africa, or to Ceylon, or to Singapore, and after April first to Tokyo. Soon the French operator Union Aeromaritime de Transport (UAT) will be operating on regular schedule. Coming closer to home, Canadian Pacific Airlines hopes to get into operation before the summer between Honolulu and Australia. (Range of this first jet transport, the Comet I, does not yet permit operation between Honolulu and San Francisco). Those who have ridden on BOAC services say that once having experienced the speed and vibrationless comfort of the jet, the passenger won't be satisfied to travel any other way again.

De Havilland Aircraft, some six years ago, embarked on the Comet design with great courage. Today they have produced most of the Comet I's and I-A's, have the Comet II in production and the Comet III in design. Only one American airline operator, Pan American World Airways, has made any firm commitments to operate a jet transport. We expect to receive three Comet III's in late 1956. By that time, De Havilland should have delivered 40 odd Comets to other airlines.

Much has been written and said about the Comet. When discussing such a new type airplane it is most important to retain perspective. There are those who would compare the Comet I most unfavorably with the latest planes from

Lockheed and Douglas: the Super Constellation L-1049E and the DC-7. Yet, neither of these airplanes is flying in service yet, and each represents the latest stage in a long line of airplane development that started with the DC-4 of 1942 and the original Connie of 1943. The Comet, on the other hand, is the first airplane utilizing the new turbojet propulsion. Comet II and III represent further stages of development and improvement over the original model.

We have reached a new phase in development of the airplane. For the last twenty years greater speeds have been obtained through the combination of decreased aerodynamic drag and increased power. It appears that further gains in drag reduction will be small. The big problem will be the extension of low drag characteristics to higher and higher speeds. We must therefore depend on development of increased power to obtain greater speed. Reciprocating engine development seems to have about run its course. Of course, there will be further refinements, and possibly new developments, but it should be noted that there is no new large reciprocating powerplant being developed by major engine manufacturers. All development is in the direction of improving existing units. This leads to the conclusion that we must depend on the gas turbine engine for higher operating speeds.

I mentioned courage before. The British, in making up their minds to go ahead with a jet transport before the end of the war, decided that the task of building an airframe around this entirely new powerplant was sufficient to demand full engineering concentration. Embarking on a research and development program to incorporate what were then highly advanced aerodynamic features was considered to impose too great risks of failure or at least severe delay, even though such a decision might limit potential capabilities of the design. So the Comet airframe was designed as a compromise to include a fairly large wing, with only moderate sweepback and moderate thickness. Compare a picture of the Comet with one of a B-47 or B-52 and you will see what I am talking about. The latter are representations of an entirely different aerodynamic philosophy, but neither appears directly convertible to commercial use, outstanding as either may be as a bomber. The Comet was a successful compromise. In one jump it achieved an increase of 150 mph, two thirds as much as had been achieved in 25 years.

It does appear probable though that the jet transport of the future will have higher wing loadings, more sweepback and thinner wings than the Comet. It is now well known that as airplane speeds approach that of the transmission of sound through the atmosphere, a phenomenon called drag rise is encountered. At such speeds, the drag coefficient of the airplane, which has changed very little with speed as it has increased from takeoff, abruptly begins to rise to much greater values. As far as present knowledge goes, it would be quite possible to design a jet transport capable of cruising at speeds higher than that of sound (760 miles per hour at sea level, 663 at 35,000 feet and above). But the economic effects of the drag rise will serve in practice to limit the speed of the jet transport for some time to come to speeds less than Mach 1 (speed of sound.). It would cost too much to operate at speeds above. Possibly some time in the future means will be found to obtain such high speeds without excessive penalty, but that seems to be in the next phase of design development.

This knowledge tends to push designers towards an airplane that will cruise as near the speeds of sound as is reasonably practicable. It would appear that we can expect speeds of 550 to 600 mph for our jet transport within the next 10 years.

What will our jet transport look like? I've already mentioned thin swept

wings. I don't think we will see a high wing, for the safety advantages of the low wing are too great. Absence of propellers would tend to bring the whole airplane closer to the ground, but pod type engine installations beneath the wing counterbalance this effect. In general, size, especially as far as hangar dimensions are concerned, it does not appear that the jet transport will be such larger. The greatest wing span yet announced is that of the Vickers VC-7 of 140 feet, which is still one foot less than that of a B-377 "Strato" Clipper. Fuselage lengths may be longer, for economic considerations seem to be encouraging greater passenger capacities. It looks like the future jet transport will carry at least 70 odd passengers in standard configuration, perhaps as high as 100. For tourist or coach services, the capacity will probably be 20-30 percent greater. In no case, however, does it yet appear that fuselage lengths will greatly exceed wing span. With swept wing designs, tail heights may be somewhat greater, but it is sincerely hoped that designers will be able to keep such dimensions within the bounds of current hangar designs. Personally, I believe 40 feet is a practical limit.

One other aspect of this future jet transport of ours. It will carry tremendous quantities of fuel. You can't make an airplane go 550 mph without using plenty of fuel. And the turbojet engine at this stage in its development is not yet as efficient thermodynamically as the powerplant it is replacing. So don't be surprised to see domestic transports with tank capacities in the 10-12,000 gallon range, and overocean airplanes with 15-18,000 gallons, compared with 7790 for the Strato Clipper. The effects on airport fuel storage and refueling problems are obvious. It will take more than two of the biggest tank trucks now in use to completely refuel one of these planes, so the underground hydrant system may be the only satisfactory solution.

Economic Considerations

Of course, much of the economic picture is in the category of educated guessing, and therefore one cannot yet be specific. But some of this picture is beginning to form, and with the experience the airlines have acquired, it is possible to make some projections. One lesson the airlines have learned since the war is that reduction in price of our product, just as in other businesses, has markedly broadened our market. Introduction of larger and faster airplanes has always resulted in greater airplane use, not less. This has naturally resulted in more and more attention being paid to operating cost estimates of the new design. Operators are almost unanimous that the jet transport should exhibit operating costs per seat mile at least as good as the best of the reciprocating engine transports. Initially this may be difficult to accomplish, with the task of adapting an entirely new type of powerplant to the airframe, but ultimately, there seems to be no reason why such costs won't be lower. Unfortunately, it appears that the new transport is going to be a very expensive article, perhaps twice as costly as the present day machine. This is traceable not only to inflationary effects, with higher labor costs, etc., but to high development costs, high cost of jet engines, and neither last nor least to the effects of size itself. Because the airplane costs so much in the first place it must be bigger to accomodate more payload.

It's an oversimplification, of course, but the best way to obtain low operating costs per seat mile is to get as many seats as practicable into the airplane, and then go as fast as possible. To continue in this most hazardous field of making predictions, it would appear to me that in order to carry these loads, and make good the speeds predicted above for desired flight ranges, the domestic type transport will have to be some 50-100% bigger than present

equipment, probably running just under 200,000 pounds maximum takeoff gross weight. The transocean plane will probably be still bigger, perhaps around 250,000 pounds. These values should be treated as initial maxima; if fuel consumption of the turbojet improves, they will be less, if the next normal airport of call is relatively close, they probably will not be reached. But if I were laying out a new international airport, I'd specify runways capable of supporting 300,000 lbs.

Of course, the most outstanding characteristic about the jet is its speed. These extremely high speeds require some adjustment in one's concept of time requirements, and historical schedule concepts may have to be altered. For example, note the comparison of flight times in the table below.

	Current Best Schedule	Comet III	Advanced J/T Design
New York-Chicago	3:20	2:40	1:55
Chicago-San Francisco	7:55	5:20	4:15
New York-San Francisco	11:45*	7:00	5:55
San Francisco-New York	10:05	5:20	4:40
San Francisco-Chicago	6:45	4:05	3:30
Chicago-New York	2:50	1:55	1:35
New York-London	11:55*	8:35*	6:00
London-New York	16:25*	12:15*	8:00
San Francisco-Honolulu	10:15	6:30	5:30
Honolulu-San Francisco	8:45	5:25	4:45

*Not non-stop. Allowance for ground time included, 30 minutes per stop domestic, 45 minutes international

All of the above figures are based on expected wind conditions. When one considers that the time difference from London to New York is 5 hours, from New York to San Francisco 3 hours, and from San Francisco to Honolulu 2-1/2 hours, the clock time differences become small indeed. For instance, we could have a leisurely lunch here in San Francisco and still be in Honolulu in time for a swim and dinner. We could spend the morning in London and still have dinner in New York. The full impact of these changes is yet to be realized, but when they become available to the travelling public, it won't be long in taking advantage of them. There is no question in my mind that these new speeds will open new sources of business for the airlines, both in passengers and cargo.

Range of the jet transport may be limited mostly by powerplant and airport considerations. Fuel consumptions of the turbojet engines require very high gross weights for long range flights; a large part of these weights being fuel. The turbojet powerplant does exhibit better specific range characteristics at high altitude, and in general, if large enough engines are provided to permit cruising at initial altitudes above 35,000 feet, they should be sufficiently large, that with moderate augmentation such as water injection, they will permit takeoffs from runways of fairly reasonable lengths.

Another major factor in the jet transport economic picture is that of engine and engine parts life. This is perhaps the biggest unknown of all, for the only experience in running engines day in day out in typical commercial operation is being acquired by BOAC. Military experience seems to be of little assistance in this respect. However, this item does not appear to be influenced by airport and airways considerations.

The overall economic picture looks quite bright. There is every reason to believe that ultimately direct operating cost per seat mile of the jet transport will be less than current costs, assuming the value of the dollar remains constant. Estimates for the Comet III show it reasonably competitive. If the jet can compete on costs, it should prove tremendously attractive, for the reciprocating airplane can't compete with speed, and will lose business to its jet competitor.

Airport Problem

Basically, the problems of adopting the jet transport to our airport system are not too complex. While it does not appear that the dimensions of the airplane will be appreciably greater than our present airplane, there are some factors to be considered. For example, with swept back wings and longer fuselage, it is quite difficult for the pilot to see the wing tip from the cockpit window. While in our specification requirements we are asking that the airplane designer provide the pilot some means of locating his wing tip while taxiing, it should be assumed that the pilot is going to have a far more difficult time, and that greater clearances at the ramp, for taxiing, etc., will be required. This especially applies to winter conditions when snow banks are often piled too close to taxiways. One other factor that should be kept in mind is that as angle of attack is increased for takeoff or landing, the wing tip of a sharply swept wing actually moves downward. Obstructions, such as runway lights, etc., would be kept well clear.

On airplanes with pod type engine nacelles suspended below the wing, the outboard engines may very well be a considerable distance from the fuselage and may not clear the ground by very much. The outer pods on a jet transport may be 70-80 feet apart and perhaps only 4-5 feet off the ground, whereas the outer nacelles of the B-377 "Strato" Clipper are only about 62 feet apart, and thin wings tend to flex more when the airplane hits a bump. This factor may actually help snow removal, providing the airplane can taxi.

To completely retract landing gear into the relatively thin wing of a jet transport, the tendency is to use multiple sets of wheels—little, if any, larger than present units. Tire pressures almost certainly will be higher. While I do not pose as an expert on reinforced concrete runway and ramp design, it would appear that the gross weights mentioned previously may impose some loading problems. Distributing the load over a four wheel truck may alleviate local pressures, but does not necessarily solve the beam bending problem. The use of pre-stressed reinforced concrete is very encouraging in this respect. Incidentally, the problem of the wet or icy runway will probably be met in part by the use of anti-skid devices on the wheels, but as yet no practical reversing device is available.

Some other airport problems with a jet transport:

Obviously, the turbojet engine creates tremendous suction in front of the engine. Parts that may be sucked into the compressor can seriously damage the engine or abrade and wear the compressor blades which will result in loss of performance. Reports to date from various manufacturers of axial flow turbojet engines indicate that foreign body damage is one of the largest single causes of premature engine removals.

This imposes on the airport operator a requirement that runway and ramps must be kept clean. Pebbles, stones various debris, etc., can seriously affect operating safety. We of the airlines also have to keep work and hangar ramp areas clean of dropped nuts, bolts, cotter pins, and other debris; this is an overall project for every one to concern himself with. More exten-

sive use of standard street sweeping equipment certainly would help. We are specifying that future jet transports be equipped with engine intake screens which will serve to minimize such damage during static and taxiing ground running. Since most screens, however, result in serious loss of thrust output when they are in place, it will be necessary to retract them before the takeoff run is commenced. Screens have to be retractable to prevent ice formation in the air. Incidentally, we shouldn't wait for jet transports to institute cleanup campaigns at airports. We already experience far too much propeller blade replacement due to damage from "foreign bodies." Regarding the effect of temperature of the jet stream on pavements, it appears that if the engine centerline clears the ground sufficiently, as would be expected in a normal transport design, excessive temperatures will not be experienced.

Fuel spillage may have a deteriorating effect on asphalt surfaces or expansion joint fillers. All fuels have tendencies to dissolve such materials, but spilled gasoline evaporates too fast to be effective as a solvent. For safety and economy reasons, it is most improbable that a fuel as volatile as gasoline will be used. Kerosene, diesel fuel, or household heating oil, all being discussed as commercial jet fuel, will not evaporate as quickly, and probably will have detrimental effects if spilled on ramp surfaces. Again, this is a joint airline-airport problem, for we operators are certainly obligated to develop of minimizing spillage.

May I digress for a moment on the type of fuel to be used in jet transports? We are giving considerable thought to this matter at this time and, in general, we feel that any fuel used for jet transport should:

1. be no less safe (primarily as determined by flash point) than ordinary kerosene.
2. have as high heat content per gallon as practicable,
3. be generally available at the airports of the world, preferably as a presently marketed product,
4. be capable of being pumped on board the airplane on the ground and from the airplane tank to the engine in all conditions of flight. This implies that certain heating must be applied to the airplane fuel system, engine filters and controls.

And it should not:

1. exhibit loss of fuel in flight due to evaporation or entrainment.
2. exhibit detrimental effects on engine reliability or appreciable increase in specific fuel consumption.

The high fuel consumption of the jet transport results in fuel cost becoming the highest single item of the airplane's direct operating cost. In an endeavor to reduce such cost, we feel it highly desirable to use a fuel with as high BTU content and as low a price per gallon as practicable. This may mean that at some airports where extremely cold temperatures are reached, some provision may have to be made for warming fuel to expedite delivery on board the airplane. Warming means should not be too complex, otherwise the cost advantages will be lost. This practice of course is not uncommon when refueling seagoing vessels. Also it is understood that some Diesel engine ships are equipped with small filtration units for removing particles of dirt, etc., from the fuel before it is used by the engine. It may be desirable

to install such filtration plants as part of the individual airport tank farm.

To start turbojet engines, considerably more power is needed than is presently required for reciprocating engines. It appears certain that the normal 28 volt ground power unit will be incapable of supplying necessary power. While we feel that each airplane should be self-sufficient, and that it be possible to start all engines without outside aid, such outside aid is going to make for quicker starts, and enable the airplane to clear away from the ramp sooner. Ground power is also needed for some of the auxiliary functions of the transport while it is on the ground: lights, air conditioning, power for checking instruments and controls, etc. It may be that the power source will be higher voltage AC power, or perhaps DC, but high pressure air supply for driving air turbines within the airplane has certain attractions. We are already using fairly large trucks to provide portable housing for our ground power supply. Putting the jet transport's ground power supply on a truck large and powerful enough to tow the airplane out to the end of the runway at reasonable speed might solve two or three problems at once. It would markedly decrease fuel requirements, for ground fuel consumption of the turbojet engines is very high. By delaying the engine start until the runway is reached, airport noise would be avoided for some five to eight minutes at least. If towing is not used, the jet transport must be able to taxi out to the runway in minimum time.

This brings us to that most controversial of subjects: Noise. There is no doubt that a jet engine is noisy.

There has been much conversation about noise of jet transports in vicinity of airports, and misconceptions about the nature of such noise are frequent. While the volume of noise from jet engines may be higher, quality of noise is not as unpleasant to the human ear as is that from a piston engine with high speed propeller. Both volume and quality of noise vary from one different type of jet engine to another, and there are some indications that the more advanced designs of greater thrust may not exhibit as unpleasant noise tendencies as some of the older, smaller engines. Incidentally, centrifugal compressor engines have been worse than axial engines, with respect to annoying compressor whine which prevails in front of the airplane. Furthermore, characteristics of jet engines are such that extensive pre-takeoff ground runups will not be necessary thereby eliminating one element of high intensity noise exposure. This will be further diminished especially with long range transports, if the airplanes are towed to the end of the runway. In the air, the jet transport's forward speed is much greater than the reciprocating engine transport; therefore, the time an observer standing below is exposed to noise is definitely less, and it does not seem to be as impressive. The times of greatest exposure are during takeoff and immediately thereafter. Final approach probably should not be as severe.

Some people seem to think that if the aviation industry really tackles the noise problem, its solution will not be far away. This is very complimentary to the industry's past record in solving extremely complex problems, but this one will not be easy to work out. The trouble is that most noise reduction devices developed to date seriously reduce performance and may introduce other hazards; for example, mufflers on aircraft engines are excellent potential fire generators. Reduced performance in takeoff and climb usually is detrimental to safety. We can't make the airplane quiet by making it unsafe.

The National Advisory Committee for Aeronautics has formed a Special Subcommittee on Aircraft Noise to organize fundamental research on the physical nature of noise; without complete knowledge in this respect, it is difficult to expect a satisfactory solution. Jet aircraft and engine manufacturers have

indicated that some improvements may be effected by detailed design changes in the engine and its installation. The airlines seem to be quite unanimous that for noise prevention reasons alone, no afterburner should be considered for commercial transports.

Also, the airline operator's maintenance work and ramp areas will probably have to be located and protected so that excess noise does not spread to the surrounding territory. It is probable that for maintenance ground runups silencer tunnels, deflectors, or other devices such as have been developed by the aircraft factories, will be desired. If these are not sufficiently successful, it may be necessary to schedule maintenance runups more carefully. Operators can do something about post-takeoff flight paths and climbing techniques, as well as using runways preferentially, to minimize noise.

A few devices have been suggested for consideration by airport designers to prevent spread of high noise levels to surrounding territory:

1. Installation of noise deflection or absorption devices such as trees, shrubbery, fences or other devices around the airport.

2. Consideration of hangar and other airport building location so that noise developed at the airport will be reflected away from densely inhabited areas.

3. With respect to new airports, or those which still have open land around them, institution of zoning regulations limiting the land to industrial or farm use. For example; it is understood that the cities of Baltimore and Amsterdam have already taken such steps.

Needless to say there is much work to be done on this subject and now is the time to get such work underway, because concrete results will not come overnight.

Runway Requirements

The turbojet engine differs primarily from the reciprocating engine in that its thrust is relatively unchanged with speed in the takeoff range. The reciprocating engine and propeller produces high thrust at zero forward speed, and while this thrust reduces as the airplane gains speed, the net thrust developed throughout the takeoff is considerably greater than that developed by the turbojet. In addition, since the turbojet depends on intake of tremendous mass flows of air for the development of its thrust, its output is more sensitive to increased temperature and altitude, both of which decrease air density. However, it does not appear as sensitive to effects of humidity.

With respect to aerodynamic characteristics, those features important for cruising at the high airspeeds necessary for efficient operation of the jet transport unfortunately do not lend themselves to improving takeoff characteristics. A high speed jet transport probably will have quite high wing loading, and thin swept back wings do not exhibit the high lift coefficients necessary for short takeoff runs. While efforts will be made to improve these features through installation of high lift devices, thrust augmentation, etc., jet transport takeoff runway requirements may not be as low as desired. In other words, if one compares takeoff performance of a 550 mile per hour jet transport capable of flying the ocean nonstop with that of a 250 mph reciprocating engined transport, the jet is going to require more runway.

It may be worthwhile to compare some actual maximum takeoff runway requirements:

Plane			DC-6B	B-377	Comet III	Advanced J/T Design
Gross Weight		lbs.	107,000	145,800	145,000	250,000
Takeoff Runway						
Sea Level	59°F	ft.	6,340	7,075	6,030	7,900
Sea Level	90°F	ft.	6,712	7,757	7,200	9,100
5,000 ft.	80°F	ft.	7,584	8,478	10,725	11,500

The Comet III and advanced jet transport design data given above are based on predicted performance, although the Comet data has background of flight test information. None of the airplanes listed is capable of taking off from 5,000 feet altitude airports at the gross weights shown.

It can be seen readily that the jet transport's takeoff runway requirements increase more markedly with temperature or with altitude than we have been accustomed with reciprocating transports. What is difficult to represent in a tabular summary is the fact that the jet transport's takeoff gross weight undergoes a greater percentage decrease as length of flight is changed, because a far greater proportion of this total is composed of fuel. The advanced jet transport considered above would have to carry about 45% of its 250,000 lbs. in fuel, whereas the DC-6B carries only about 30%. This means that not all airports need 10,000 or 9,000 foot runways to permit jet transport takeoffs. Flights from coastal to inland cities, or along the coasts, are not going to require the fuel loads that are required on coast to coast flights, or on international flights. Of course, the airport at higher altitudes, or located where high temperatures prevail during the summer will have to provide longer runways than its low altitude or more temperate neighbor. So, in part at least, geographical location of an airport is going to influence the length of runways required for jet transports.

One note of warning to airport design engineers. Sloped runways will have greater detrimental effect on the jet transport than on present reciprocating aircraft, because of the jet's poorer acceleration qualities at low speed. Believe it or not, there are runways in this world that have so much slope that even currently operating aircraft have difficult in clearing because initial climb gradient is only slightly greater than runway gradient.

On the subject of assisted takeoff, it seems to me that this will be reserved for special situations, and then probably only for use in event of emergency. The practicality or economic features of most of these devices are such that the average operator is reluctant to use them. Also, if assisted takeoff, or too great thrust augmentation were resorted to to get the jet transport off the ground, it would undoubtedly be found that the altitude performance deteriorates so much that the higher takeoff gross weights are not justified. The jet transport must fly high to obtain optimum miles per pound of fuel.

Again getting into the field of predicting requirements, I do not see reasons why runways longer than 10,000 feet will be needed for international express jet transports operating from sea level airports. On the other hand, it will be most difficult with present knowledge of the art to design an economically efficient jet transport capable of landing in less than 5,500-6,000 feet runways. As I will endeavor to explain below, landing requirements become more restrictive for short ranges than do the takeoff requirements.

Experience with reciprocating transports has indicated that takeoff runway requirements are usually more severe than landing requirements. For jet

transports, wing designs necessary for efficient, economic jet flight may not produce the high lift features necessary for short landings. Normally, landing runway requirements are determined by lift coefficient available and magnitude of this coefficient is indicated--inversely--by stalling speed; i.e., low stalling speed--high lift coefficient and vice versa. In this stage of development it appears quite difficult to design an efficient jet transport with stalling speed much less than 100 mph. Of course, some current piston engine transports are already flying with stall speeds in excess of 100 mph. Normally when the pilot throttles his engines on a propeller airplane, the propeller and engine come back into a condition where the windmilling of the propellers actually imposes a drag on the airplane. Even at idling the jet engine develops a small amount of positive thrust. The jet transport is aerodynamically very clean and in addition to low lift coefficient has much lower drag than older aircraft. Therefore, the jet has a tendency to "float" and usually will be unable to make as steep an angle of descent as its predecessor. This problem is well recognized and in time there may result improvements in this direction, but the trend is for the jet transport to require longer runways for landing.

The tabular summary below shows this trend for the same airport conditions as for takeoff:

		DC-6B	B-377	Comet III	Advanced J/T Design
Max. Landing Weight	lb.	88,200	121,700	100,000	140,000 (?)
Landing Runway					
Sea Level 59°F	ft.	5,150	6,420	6,600	6,100
Sea Level 90°F	ft.	5,150	6,420	6,900	
5,000 ft. 80°F	ft.	5,885	6,900	7,850	7,350

Note: Present regulations do not require any adjustment in landing runway requirements for temperature but it is possible that future regulations may.

The landing problem reverses the trend of the takeoff problem and actually becomes less severe for long range flights than short range. This results from the fact that landing gross weight is composed of the sum of the airplane's equipped weight empty, plus reserve fuel requirements, plus payload. For short range flights, reserves may be less, but payloads normally are so much higher that the operator usually runs into landing gross weight restrictions on short haul. Geographic location of the airport will be of little assistance in reducing runway requirements for landing.

Unfortunately, no practical means has been found yet to successfully reverse thrust from a jet airplane. While reversing propellers have not been utilized to reduce landing runway requirements for propeller driven transports, the availability of the reversing feature is a potential safety device on high stall speed airplanes. Research has been undertaken and perhaps sometime in the future some type of reversing will be available, but in any event cannot be counted upon for reduced landing runway requirements. Research on development of improved high lift devices, spoilers for improving effectiveness of brakes, and other aerodynamic devices has shown more promise. It appears probable that jet transports will be equipped with tail drag chutes for coping with an emergency or landing on ice-covered runways, but the chute is not completely satisfactory, for it must be used early in the landing

roll to be effective, and satisfy the condition of slippery runway with cross wind.

Airways

Most of the problems of transition from reciprocating engined to turbojet transports over the airways are not those which normally concern the civil engineer. The jet transport will unquestionably fly at much higher altitudes: 35-45,000 feet, removing most of the terrain clearance problem, except in climb and descent. Some new problems are introduced, for little is known of actual day to day meteorological conditions at such altitudes. Some wind data are available; these indicate that much higher velocity winds must be expected. Effects of conservatively expected winds are shown in the flight times given earlier. If winds in actual service prove to be considerably greater in velocity, range requirements for the jet transport will be increased, which in turn will mean higher gross weight and higher takeoff runway requirements. If peculiar meteoroligical conditions such as jet streams force diversion from planned routes or altitudes, the range requirements will be increased. Even less is known of temperature conditions prevalent at such altitudes. Higher temperatures tend to reduce available range, and may thereby influence takeoff requirements.

The jet transport is also somewhat more sensitive to climb, holding, and descent conditions. If a Comet III is required to hold 5 minutes at 1,000 feet on 2 engines, it will consume 715 lbs. of fuel. This overall problem has received so much attention, however, that there appear to be ways and means to cope with it adequately. Installation of more precise ground and air radio aids will enable the pilot to make the flight with greater precision and schedule arrival at terminal airports more accurately. This will permit fitting into the approach and landing pattern with less delay. If the jet transport can accomplish holding at relatively high altitudes, say 15-20,000 feet, and then make a fast descent to the airport, much fuel reserve will be saved. Pressurization systems on jet transports should be capable of maintaining sea level cabin pressure up to 20,000 feet or more, therefore, such rapid descents should cause no discomfort to passengers other than possibly the acute angle of approach and there is some promise that even this can be held to reasonable minimum.

It is also probable that holding can be executed at such altitudes or perhaps higher, with one or more engines temporarily shut down to be restarted before approach. This will save fuel. The airport designers should be interested in any way and means that savings can be obtained in enroute or reserve fuel because both participate in the establishment of takeoff and landing runway requirements. It is my feeling that if improved radio aids can be installed in the airplane which can contribute to better navigation and therefore reduced reserve requirements, the expense and weight of the equipment will be justified, providing of course that they are kept within some reasonable bounds.

The jet transport will probably require improved radio aids for enroute navigation. There has been an old saying in the industry: "Aviation is not inherently unsafe, but like the sea it is terribly unforgiving of any carelessness or neglect." It appears that the problem of long range of navigation of jet transports can be expressed similarily, in that it probably will be difficult to make a mistake in navigation, but if such a mistake is made the results can be of far greater consequence.

Concluding Remarks

It is my hope that I have been able to cite some of the problems incurred in making the transition to jet transports, and some suggestions as to their solution. I would not want to leave the reader with the impression either that these are all the problems or that all of the items mentioned herein may turn out to be actual problems. It is my feeling that the overall subject should be approached in the same manner as any other major engineering project with optimism, courage, and patience. Successful solution will result from joint action on all phases by airplane, powerplant and airport designers; operators; flight and maintenance personnel; and any others who have any connection whatsoever with the problem.

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